



General Assembly

Distr.
GENERAL

A/AC.105/493
23 December 1991

ORIGINAL: ENGLISH

COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

REPORT ON THE UNITED NATIONS/FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS/EUROPEAN SPACE AGENCY WORKSHOP ON
MICROWAVE REMOTE SENSING TECHNOLOGY, ORGANIZED IN COOPERATION
WITH THE GOVERNMENT OF SPAIN

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INTRODUCTION

A. Background and objective

1. At its thirty-seventh session, in its resolution 37/90 of 10 December 1982, the General Assembly endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and decided, among other things, that the United Nations Programme on Space Applications should promote the dissemination of information on advanced space applications and new systems developments among managers and decision makers, particularly for the benefit of the developing countries.

2. The United Nations/Food and Agriculture Organization of the United Nations/European Space Agency Workshop on Microwave Remote Sensing Technology was one of the activities of the programme for 1991 that were endorsed by the General Assembly in its resolution 45/72 of 11 December 1990. The Workshop was held in cooperation with the Government of Spain and hosted by the Instituto Nacional de Técnica Aeronáutica (INTA) at its Maspalomas Space Station in the Canary Islands, Spain, from 10 to 14 June 1991, for the benefit of participants from the Economic Commission for Africa (ECA) and the Economic and Social Commission for Western Asia (ESCWA) regions.

3. The objective of the Workshop was to expose the participants to various aspects of current and future microwave remote sensing systems, including the acquisition, processing, archiving and applications of the data generated by such systems. The presentations delivered at the Workshop provided an overview of microwave remote sensing, the physical principles of image formation and the interpretation and analysis of the elements involved in applications of radar data to tropical forest environments, agriculture, hydrology and oceanography. The experiences and programmes of some countries, including those from the ECA and ESCWA regions, in the use of microwave remote sensing, were also presented. The Workshop concluded with working group deliberations that focused on three major areas - data availability and accessibility, education and applications development.

4. The present report, which covers the background, objective, organization, observations and conclusions of the Workshop as well as a summary of the lectures presented, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants will report to the appropriate authorities in their respective countries.

B. Organization and programme of the Workshop

5. The participants were professionals with several years of experience in remote sensing or in developing plans for the management of natural resources and related programmes that can benefit from the applications of microwave remote sensing. The Workshop was attended by 34 participants from the

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following Member States and international organizations: Canada, Egypt, Ethiopia, Ghana, Guinea-Bissau, Jordan, Kenya, Mauritania, Nigeria, Saudi Arabia, Sierra Leone, Spain, Syrian Arab Republic, Tunisia, Uganda, United Republic of Tanzania, United States of America, ESA, FAO and the United Nations (Outer Space Affairs Division).

6. Funds allocated by the United Nations, FAO and ESA for the organization of the Workshop were used to defray the cost of international air travel and daily subsistence allowance of 17 participants. The Government of Spain, through INTA, provided the conference facilities and local transportation for all participants.

7. Opening addresses were presented by Mr. Julio Melian, Director, INTA-Maspalomas Space Station on behalf of the Government of Spain, by Mr. J. F. Dallemand on behalf of FAO and by Mr. Sergio Camacho on behalf of the United Nations; a statement on behalf of ESA was also read at the opening ceremony.

8. The programme of the Workshop (see annex below) was developed jointly by the United Nations, FAO and ESA in consultation with INTA. The Workshop was conducted through a number of plenary and working group sessions. At the latter, the participants discussed the issues associated with microwave remote sensing and concluded the sessions with the following observations and recommendations.

I. OBSERVATIONS AND RECOMMENDATIONS OF THE WORKSHOP

9. The deliberations of the Workshop during its working group sessions focused on the following three major areas of microwave remote sensing: (i) data availability and accessibility, (ii) education, and (iii) applications development. The discussions included references to the experience acquired in satellite microwave remote sensing by the international scientific and user communities from experimental missions such as the oceanographic mission of SEASAT (1978) satellite and the more recent Shuttle Imaging Radar missions, SIR-A (1981) and SIR-B (1984) conducted by the National Aeronautics and Space Administration (NASA) of the United States of America.

Data availability and accessibility

10. The participants indicated that for countries in the ECA and ESCWA regions to be able to implement existing plans for rapid social and economic development, it would be necessary for planners and decision makers to have accurate and detailed information on the resources of a country. Reliable, up-to-date and timely maps and thematic cartography are essential for this purpose. However, in the ECA, and to a lesser degree in the ESCWA region, there is a lack of such information, particularly at scales of 1:50,000 or larger. The availability of data from satellite sensor systems, airborne observation platforms and various ancillary sources is vital to redressing this situation.

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11. Satellite and aircraft remote sensing data obtained in the visible and infrared regions of the electromagnetic spectrum have been available for at least two decades. The contact points and the mechanisms to access these data are well known to the scientific and user communities. In particular, during the Workshop the participants were made aware of Earth Observation Satellite Company's (EOSAT) new policy that would provide, at marginal cost, data that are two or more years old from the LANDSAT series of satellites. The participants indicated that such a policy would facilitate their use of LANDSAT data for many of their research and applications activities.

12. Beginning with the launching in July 1991 of ERS-1 by the European Space Agency and continuing with the ALMAZ satellite to be launched by the Union of Soviet Socialist Republics (1992), Japan's JERS-1 (1992) and Canada's RADARSAT (1994), there will be a continuous supply of satellite-obtained microwave data for at least the next 10 years. Other microwave data sets, obtained by airborne radar over several countries of the ECA and ESCWA regions for specific projects, may also be available to the scientific and user communities of the regions.

13. In order to benefit from the all-weather and day/night capabilities of microwave remote sensing, countries and institutions should explore various ways of identifying the data that is or will be available, the sources or repositories of the data and the means of obtaining access to such data. A list of contact points for receiving stations that cover the ECA and ESCWA regions should be prepared by one of the regional remote sensing centres and distributed through the ECA Remote Sensing Programme, while ESCWA headquarters could be requested to coordinate a similar effort for its region.

14. However, participants noted that although a number of steps could be taken that would make microwave and other types of data more readily available, the issue of having access to these data is more difficult to resolve. A researcher or a user who tries to access/purchase data often encounters difficulties which are due to the decision maker in their own country not being aware of the need to make long-term and sustained commitments in the field of remote sensing.

15. In many countries, access of the local scientific community to satellite-acquired, cartographic and ancillary data, is limited by regulations introduced by their own Governments. These regulations are usually based on a national security concept which has been developed by authorities who are most often uninformed about the observation capabilities of satellite sensor systems. While such a policy also ignores the "open skies policy" followed by the satellite operators, it imposes limitations which can only be enforced to the detriment of their own scientific and user communities although the data is available to the international community.

16. The cost of remote sensing data has increased by a factor of 10 during the last decade, making it more difficult for the user and particularly, the university research community to have access to it. However, the availability of data by itself has very little impact on a country's development if the

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educated and trained personnel, governmental/institutional support and adequate infrastructure are not in place. Rather than cost, the main obstacles in gaining access to data include a lack of clear understanding of the type of data to request, how to use it for a specific purpose and convincing the decision maker that acquiring it is a worthwhile investment.

17. Thus, it is the responsibility of the remote sensing, photogrammetric and cartographic communities, within the academic and government institutions, to sensitize the policy makers in their respective countries about (a) the potential contributions and limitations of remote sensing applications to the social and economic development of the country; and (b) the need to educate and train, on a sustained basis, the individuals that would use the technology. Accomplishing such tasks will also be dependent on the knowledge and understanding of the user community itself.

18. The working group analysed two situations that illustrate that factors other than cost are important obstacles in obtaining and utilizing remote sensing data. As part of the United Nations/International Space Year activities, the United Nations and ESA offered to provide, free-of-charge, historical satellite data sets over a few selected sites located in countries in Africa that are covered by the Maspalomas (Canary Islands, Spain) or Fucino (Italy) satellite-receiving stations. Such an offer was made through a "Request for Proposals (RFP)" of ongoing projects that could benefit from the information contained in the data sets. The responses to the RFP were weak both in terms of the number of proposals received as well as in terms of the proposed uses of the data. The second situation involved a different RFP sent by ESA in order to select Principal Investigators for research on its ERS-1 images whereby the selected investigators would receive ERS-1 data free of charge. This RFP also resulted in a similarly weak response from the research communities in the ECA and ESCWA regions.

19. The participants concluded that in both situations one of the problems was that the relevant information did not reach the appropriate institutions, agencies or individuals. In general, such offers or information are channelled in a country through its ministry of foreign affairs or economic planning, from where it is routed to one or a few institutions which may or may not be the most relevant ones for the particular situation.

20. A list of key contact points at the national level for each major area in remote sensing should be prepared and made available to the ministries through which most offers to participate in international research or applications projects are received. The list of national contact points should also be made available to regional and international organizations as well as to designated regional contact points. Each country would have to prepare its own list which should also be distributed among all the concerned institutions in order to build an effective network of institutions and individuals within the regions.

Education

21. Throughout the ECA and ESCWA regions, remote sensing education and training are conducted at universities, national and regional centres and at user institutions, mainly in connection with ongoing research or applications projects. Although there are a few courses on the principles of remote sensing, most established university courses are in the fields of photogrammetry and photointerpretation. Training and education in remote sensing are generally obtained through on-the-job training, interaction with foreign experts who are participating in local projects or, in the case of a few individuals, through education at remote sensing institutions, mostly abroad.

22. In order to develop an indigenous capability, the participants emphasized that many more elements of remote sensing education need to be included at universities in the ECA and ESCWA regions. The participants welcomed the initiative of the United Nations to establish regional centres on space science and technology education that would initially provide in-depth education in remote sensing. This educational programme would be provided primarily to university educators from the relevant basic research and applications areas and should thus have a multiplying effect.

23. The launching of ERS-1 and the preliminary examples of the application areas of its images stress the continuous advance of space science and technology. Education and training in remote sensing should likewise be continuous activities within the ECA and ESCWA regions. In the case of short-term education and training, there is a need to develop continuing education programmes for remote sensing professionals who cannot separate themselves from their activities for prolonged periods of time. For individuals who already have a background in remote sensing, the programmes should address mathematical modelling methods, digital image processing, geographic information systems (GIS) and the fundamentals and interpretation criteria of radar images. For individuals who are working on specific, time-limited projects, there is a need to identify the content and level of short-term activities that would prepare them to fulfil their duties. Both of these types of programmes should be organized by the universities and by the national remote sensing centres. Where financing can be found, it is also desirable to hold these activities at the regional centres.

24. Through education, an individual acquires an in-depth knowledge of a field of science and of the technology associated with it. Thus, the individual is prepared to analyse a given problem and to contribute to its solution by utilizing the technologies that are available in his/her environment. Since such long-term education is conducted primarily at universities, those institutions that already have remote sensing education programmes should strengthen and bring them up to date to include the theory and applications of new developments such as microwave remote sensing. Universities should also address the major space-related global issues, such as the "greenhouse effect" and global climate in order to provide guidance for national policy and to contribute to the international debate and solutions on these issues.

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25. Universities and other institutions of higher education should establish cooperation mechanisms to share experiences on long-term education programmes. An initial step could be the preparation of a directory containing a listing of the courses offered at each institution and addresses of the respective contact persons. The institutional contributions to this directory can be prepared at the national level and subsequently integrated in a single document by a lead university in each of the ECA and ESCWA regions. The complete directory should be distributed to all institutions of higher education in each region.

26. Adequate bibliographic and reference materials are necessary for both the long- and short-term education and training activities. In many institutions of higher education of the ECA and ESCWA regions, there is a need for textbooks, reference books and manuals and recent periodicals dealing with remote sensing and other related areas. Mechanisms should be found to link potential donors of such materials with the libraries who would receive them. Universities, either individually or collectively through a region's association of universities, should contact institutions or organizations with ongoing or planned book donation programmes such as the one being operated by the International Centre for Theoretical Physics and the Third World Academy of Sciences (ICTP/TWAS) Book Donation Programme.

Development of applications

27. It is necessary to strengthen support both for education programmes in remote sensing and for its utilization in the priority areas within the established national economic and social development programmes.

28. Successful applications projects that show an advantageous cost/benefit ratio when compared to conventional methods or results that would not be possible to obtain without the use of remote sensing, are an excellent means to convince the decision makers of the need for significant and sustained support. To promote support for microwave technology, reference should be made to successful applications of remote sensing data available in the past, with indications of the additional information that could be extracted from radar images, including their all-weather capability.

29. There are a number of applications in which the use of radar remote sensing is particularly capable of providing information that is not currently available due to the characteristics of the terrain or to the prevailing weather conditions. Examples of these applications include the mapping of wetlands in Kenya and Uganda and urban development planning in tropical countries.

30. In addition to local efforts, there will be possibilities to participate in the applications of microwave remote sensing in demonstration-of-capability and pilot projects conducted at the international or regional levels. In order for countries in the ECA and ESCWA regions to benefit from these international opportunities, it is necessary that local researchers develop their skills in the preparation of project proposals. A good knowledge of the

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technology will be necessary in order for them: (i) to prepare a concise project definition; (ii) to indicate the facilities and human resources available; and (iii) correctly to stipulate the type and amount of radar data that would be required.

31. A programme that could provide the basic surveying and mapping services necessary for inventories of natural resources, management of water resources, improvement in land use and urban planning and the management and preservation of the environment, would create a receptive local environment for other remote sensing education, research and applications programmes or projects. The appropriate government authorities of each country in the ECA and ESCWA regions should embark on such a long-term programme with the goal of providing within the next 10 to 15 years, the basic cartographic products that are essential to their priority development areas.

32. There is a need to finance research projects which could further the development of in-depth knowledge that is required for successful applications projects. However, most financial support for projects, from both national and international sources, is provided for applications projects that have the potential to deliver specific services or products. It is the responsibility of the scientific and user communities to sensitize the national planning and programming authorities of the need to finance basic research. This effort can best be conducted by established national science councils, academies of science or related professional societies. These academic bodies should also compile and disseminate information on all national and international sources of financing including the type of projects and fields of specialization for which support is provided as well as the addresses of the contact persons.

II. SUMMARY OF PRESENTATIONS

A. Overview of microwave remote sensing

33. Remote sensing of the Earth, from both aircraft and satellite-borne sensors, has proved to be a useful tool for surveying, evaluating and monitoring natural resources, various land use features and the environment in general. Most of the experience that has been accumulated to date by the international research and applications communities has been in the use of data obtained in the visible and infrared portions of the electromagnetic (EM) radiation spectrum. The observation of the Earth in this range of wavelengths (i.e. 0.4 to 14 micrometres) is based on measurements of either the reflected or the emitted radiation by objects on its surface. Therefore, in the visible and infrared range, sensors ultimately depend on the Sun as the source of energy that is received by them.

34. Because of the absorption characteristics of the atmosphere, measurements of radiation in the visible and near infrared range require clear-sky, daylight conditions. At the long end of the infrared range, the radiation is due to the temperature of the body being observed. Thus, the radiation observed from a cloud-covered area of the Earth is due mostly to the cloud

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temperature and not to the ground features. Consequently, for regions of the Earth with persistent cloud cover (e.g., tropical areas), the amount and timeliness of the information that can be remotely obtained in the visible and infrared range of the EM spectrum are severely limited.

35. Microwave remote sensing provides the capability for day or night observations and under clear sky or cloudy conditions. This is possible because most microwave sensors provide their own source of radiation (i.e., independent of the Sun) and because microwave radiation, which is in the 1 mm to 1 m portion of the EM spectrum, can penetrate through clouds.

36. Microwave sensors can be classified into passive and active systems. Passive systems measure microwave radiation emitted by the ground features or emitted by the Sun and reflected by the surface. Active systems "illuminate" the area under observation and measure the strength and time delay of the radiation that is reflected by the ground features.

37. Microwave instruments used for remote sensing fall into one of the following four categories: (i) microwave radiometers used for emitted radiation measurements; (ii) radar scatterometers used to obtain point-type information such as sea-state; (iii) radar altimeters used as ranging instruments to measure altitudes above sea level and heights; and (iv) imaging radars that can produce geographic information about the area being observed as well as provide information on the characteristics of the objects present in the image. Imaging radar instruments have found the greatest variety of applications. The geographic character of these images permits the user to superimpose (register) them on existing cartography or imagery obtained in the visible or infrared portions of the EM spectrum.

38. The interaction of microwave radiation with objects on the surface of the Earth depends strongly upon the electrical properties of the objects and the surface roughness relative to the wavelength of the incident radiation. The electrical properties of matter are determined by its dielectric coefficient, which is highly sensitive to water content. An analysis of the returned signal can therefore provide information on the nature of the objects, their relative size, distribution and moisture content.

39. Radar images can be obtained from either an aircraft or a satellite. In both cases, the images are obtained by transmitting microwave pulses at an angle to the vertical and measuring the intensity and time delay of each returned pulse. The first return pulse corresponds to the object whose projected distance in the direction of the sensor system is the smallest. In general this pulse corresponds to the object closest to the flight path. Because of the geometry between the incident pulse and the height of objects, the projected distance in the direction of the sensor system of the upper part of an object is smaller than the distance of its corresponding ground-point projection. This effect is known as foreshortening and makes terrain of high relief appear in the image as falling towards the radar. On the images, foreshortening causes the slopes to become extended and to appear darker. This effect can be corrected with reference to a digital terrain map.

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40. The foreshortening effect can become very severe so that the top of a mountain appears to be closer to the flight path than the foot of the mountain. This effect is called layover and cannot be corrected. Other image degradations include a speckle effect, which appears as noise on the image and is related to the frequency coherence of the system, as well as several effects due to the motion of an object with respect either to the sensor system or to other objects in the field of view of the radar.

41. Because the difference in distance between objects directly beneath an aircraft or a satellite is very small, the corresponding return signals cannot be electronically discriminated. For this reason airborne radars have been designed to scan objects at some distance to one of the sides of the aircraft and are called side-looking airborne radars (SLAR). The spatial resolution attainable from a radar system is independent of the altitude of the sensor platform and increases with the length of the antenna that transmits and receives the microwave pulses. A technique known as Synthetic Aperture Radar (SAR) which applies a linear frequency modulation to a transmitted long pulse in order to simulate a train of short pulses has been developed in order to keep satellite antennas reasonably small. The technique uses the Doppler shift of the reflected pulse due to the motion of the platform and a modified data processing to simulate a much longer antenna. The result is a higher resolution which is only limited by the power that the antenna is capable of transmitting.

42. The microwave spectrum is subdivided into various bands, each of which is referred to by a single letter character and is determined by a specific range of frequencies as follows:

<u>Band name</u>	<u>Band limits (GHz)</u>	<u>Band name</u>	<u>Band limits (GHz)</u>
P-band	0.225-0.390	K-band	10.90-36.00
L-band	0.390-1.550	Q-band	36.00-46.00
S-band	1.550-4.200	V-band	46.00-56.00
C-band	4.200-5.750	W-band	56.00-100.0
X-band	5.750-10.90		

For airborne radar missions, which account for the bulk of the microwave data gathered world wide to date, the most used bands have been the X-band and the K-band. For the satellite radar systems of the 1990s, the predominant frequency will be the C-band.

B. Data acquisition and processing

43. Launched in July 1991, ERS-1 is a low orbit Earth observation satellite with several microwave sensors on board. The primary mission of ERS-1 is to increase the understanding of ocean processes, to monitor the polar regions and to contribute to the World Climatology Research Programme. However, land-oriented applications will soon result as the international research community has access to the data. The primary instrument on board ERS-1 is

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the Active Microwave Instrument (AMI) which can provide high resolution images (C-band), wind speed through ocean wave spectra analyses and the length and direction of ocean waves. Operating in the imaging mode, the AMI covers a swath 80 to 100 km with initially assessed resolutions of 27 metres in range and 29 metres in azimuth.

44. Operating in the wind mode, AMI covers a swath of 400-500 km over the ocean with resolution cells of 50 km and measures wind speed in the range of 4 to 24 m/s with an accuracy of 0.5 to 2 m/s. Wind speed and direction are determined by measuring the strength of the backscattered signal of each resolution element from three directions: obliquely ahead, to the side and obliquely behind the satellite path. The intensity of the three signals provides the wind speed and the differences between them indicate the wind direction with an accuracy of 20°. In wave mode operation, AMI determines the length and direction of ocean waves in 5 by 5 km cells for segments of 200 to 300 km along the satellite path. Wavelengths of 100 to 1,000 m can be measured to an accuracy of 25 per cent and their direction to an accuracy of 20°.

45. In addition to the AMI, ERS-1 carries a Radar Altimeter (RA) that operates at a wavelength of 2 cm. This altimeter looks vertically downward to measure average wave height, wind speed and to determine the meso-scale ocean topography. Data from this altimeter will also be used to determine ice type and topography as well as the water/ice boundaries. ERS-1 also carries an Along Track Scanning Radiometer (ATSR) that operates in three bands in the thermal infrared region; these bands are centred around 3.7, 11 and 12 micrometres. The ATSR looks through the atmosphere at the surface of the ocean from two directions, downward vertically and at an incidence angle of 50°. The difference between the oblique and vertical measurements provides information on atmospheric absorption while the difference between measurements at the three wavelengths are used to determine atmospheric water vapour content.

46. ERS-1 data is received by ESA's network of ground stations which include Maspalomas (Spain), Kiruna (Sweden), Fucino (Italy) and Gatineau (Canada) as well as by a number of ground stations located in the industrialized and developing countries. User requests for acquisition of ERS-1 data over a particular area of the Earth or requests for specific products of ERS-1 data already acquired, are channelled through ESA's Earthnet Central Facility (EECF) located in Frascati, Italy. The EECF supports the cataloguing and archiving of ERS-1 data acquired and provides a browse option that is available to the users.

47. Other SAR data, obtained by the SEASAT satellite (1978), the Shuttle Imaging Radar-B (SIR-B) and Aircraft SAR (AIRSAR) missions of the United States is kept in the archives of the Radar Digital Processing Group at the Jet Propulsion Laboratory (JPL). Information on the characteristics of the missions and on the data obtained by them can be accessed through JPL's SAR Data Catalogue System (SDCS) from a remote terminal. The SDCS also contains an on-line inventory of the digital terrain data in the archives at JPL.

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information on other ancillary data sets (i.e. data typically used in conjunction with SAR data analysis and interpretation) will become available as the data are acquired.

C. Applications to tropical forests

48. Tropical forests are one of the Earth's most valuable resources. From an ecological perspective, they play a major role in the hydrological cycle and in recycling atmospheric carbon dioxide. They stabilize soil and prevent excess runoff of silt and dissolved substances into streams. Their effects on climate through energy and water exchange with the atmosphere are not well understood but are expected to be significant. Much of the Earth's species diversity is represented by the plants and animals which make up tropical forest biomass.

49. For most tropical countries deforestation has become a drain of an increasingly valuable resource. Local and overseas interests alike have over-exploited forest resources. While it is apparent that improved management of tropical forests requires substantial economic, political and institutional changes, it also requires additional information about the forests themselves and changes which are happening in and around them. Much of the additional information can be supplied by satellite and airborne remote sensing systems, with adequate field checking.

50. Numerous studies of the application of radar remote sensing in the tropics have been carried out since the late 1960s. Regional and nationwide surveys in South-East Asia, Africa and Central and South America to date exceed more than 15 million square kilometres in areal coverage. Most of the tropical experience with radar has been in the form of "on-the-job learning" as part of operational surveys, in contrast with temperate latitude studies, which have been generally of a formal research nature.

51. Numerous regional and national tropical vegetation surveys have shown the applicability of radar data to specific types or conditions of vegetation. In particular, major vegetation formations, including savanna, dense and open tropical forest and woodlands, have been identified on radar imagery. Published reports have also shown that mangrove forest environments can be mapped accurately because of their strong radar backscatter compared to the surrounding forest stands.

52. The aircraft of the Jet Propulsion Laboratory (JPL), using the C, L and P-bands, completed a series of flights over Belize in 1990 allowing a direct comparison of the usefulness of the three bands for tropical forest applications. The results showed that the image contrast for forested/deforested boundaries increased with wavelength. There is also a decrease in mean reflectivity at C-band wavelengths with increasing angle of incidence of the microwave radiation. This effect could prove useful as a discrimination element for data available over a range of incidence angles, as will be the case of Canada's RADARSAT data.

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53. Although C-band data will be the most abundant data to be obtained from operational systems for the next decade, they are not the best data for tropical forest applications. Results from the limited C-band data available show little discrimination between undisturbed tropical forests and older deforested areas or dense plantations. The results also indicate that C-band radar rarely penetrates through foliage in closed moist forests. The experiments of the JPL mission referred to above also show that the P-band has the greatest potential to differentiate between the canopy's foliage, the standing timber and the surface beneath the forest. These differentiations improved when the polarization of the incident and reflected radiation was considered.

D. Applications to hydrology

54. Because of its capability to measure directly the state of the system, microwave remote sensing offers unique possibilities for weather, climate and hydrological studies. Measurements of water vapour content, snow water equivalent and soil moisture are examples of atmospheric and hydrologic state variables that can potentially be measured by microwave sensing. In other regions of the EM spectrum, except for thermal sensing, the geophysical variables must be inferred since they cannot be measured directly.

55. Remote sensing for atmospheric and hydrological processes is usually carried out at frequencies near the peaks and valleys of the atmospheric attenuation curve. Measurements near the resonant peaks are used primarily to determine atmospheric temperature or water vapour. Such measurements (around 22 GHz) can either provide estimates of the total water content in a column of the atmosphere or be used to correct for the effects of atmospheric attenuation in the sensing of other parameters.

56. Measurements in the valleys of the atmospheric attenuation curve are ideally suited for monitoring the Earth's surface. Such measurements include sea surface temperature (SST), snow cover, concentration of sea ice and soil moisture. For example, SST measurements have been made at 18 and 37 GHz, snow cover at 37 GHz and soil moisture at 6 and 1.4 GHz. At the lower-frequency (i.e., longer-wavelength) end of the microwave spectrum, the radiation emitted or reflected by matter is generally determined by its bulk dielectric properties. This implies that the measured radiation contains information about the inner structure of the bodies being sensed.

57. Passive and active microwave observations can provide direct measurements or estimates of rainfall rates. The physical basis for passive measurements fall into two regimes: absorption and scattering. In the absorption regime, rainfall is observed through the enhanced microwave emission associated with the raindrops against a cold background. This technique is only applicable over the surface of the ocean. In the scattering regime, rainfall is observed through enhanced microwave scattering (due to the raindrops) which can be measured against any surface background.

58. Soil moisture can be defined as the temporary storage of precipitation within a shallow layer of the Earth that is generally limited to the zone of aeration or root zone. Although the amount of water in this layer may appear to be insignificant when compared to the total amount of water available on a global scale, it is this layer that controls the success of agriculture and regulates the distribution of precipitation between storm runoff and storage. In spite of its importance, soil moisture is seldom used in the prediction and monitoring of crop productivity and water resources because of the difficulty in its determination.

59. Soil moisture is highly variable both spatially and temporally as a result of the inhomogeneity of soil properties, topography, land cover and non-uniformity of rainfall and evapo-transpiration. Soil moisture is difficult to measure, by any means, in a way that is representative of large areas; such measurements are only valid at the "point" where they are obtained. Although averages of point measurements of soil moisture are used to characterize an area, these averages seldom yield information that may be representative of other hydrologic processes (e.g., evapo-transpiration or runoff ground-water recharge).

60. Microwave measurements of soil moisture are based on the large contrast between the dielectric properties of liquid water and dry soil. For many hydrologic applications, changes in soil moisture may be more important than the actual absolute value of the soil moisture. Although not a truly operational technology, remote sensing of soil moisture has been shown to be feasible through a number of research projects. A great deal has been learned from those studies, but additional work is needed to define the optimal sensor configurations.

61. Evapo-transpiration is the combined loss of water through the process of evaporation from water surfaces and bare soil and transpiration from the canopy cover. The crucial role of evapo-transpiration at regional or global hydrologic scales has only recently begun to be understood. Climatic simulations using global models now demonstrate that precipitation is sensitive to regional evapo-transpiration magnitudes.

62. Known remote sensing techniques are not applicable for measuring evaporation and transpiration. The values and the rates of change of the latter depend on the initial soil moisture, atmospheric conditions, the characteristics of the surface and the incoming solar radiation. The evaporation rate is controlled initially by the availability of energy at the soil surface. As the soil surface dries, the rate decreases and is controlled by the transfer of water to the surface. Transpiration from a canopy depends upon the soil moisture available in the root zone and on the energy input into the system. Thus, evapo-transpiration values are estimated from visible and infrared measurements to identify land cover and to estimate photosynthesis rates as well as from microwave data to characterize the surface and to estimate soil moisture.

63. Snow has two major roles in the hydrologic cycle: (i) snow melt is the principal source of water for runoff and soil moisture recharge at high

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latitudes and high altitudes; and (ii) snow cover influences the global climate; even small areas in mid-latitude mountains may also be sensitive indicators of climate change. Visible and infrared data do not provide accurate estimates of snow water equivalence (the crucial value in snow hydrology), partly because snow depth cannot be measured in this spectral range. In addition, because rapid snow melt often occurs in cloudy weather it is important to be able to have all-weather capability to determine the snow-covered area.

64. Microwave remote sensing can provide information on the snow pack properties of most interest to hydrologists: snow-covered area; snow/water equivalent; and the presence of liquid water in the snow pack, signalling the onset of the melt. The potential of microwave sensing is based on its sensitivity to the presence of even minute quantities of liquid in the snow which drastically change its dielectric coefficient.

E. Applications to oceanography

65. Microwaves incident on the ocean are scattered in many directions. A portion of the scattered energy, which carries information on the sea surface and upper layer (0.1 mm to 10 cm) of the ocean, is received by the radar. The intensity of this return signal is dependent on the viewing angle of the radar, frequency and polarization of the radiation, electric properties of the sea and particularly on the sea surface roughness relative to the wavelength of the incident radiation. In processing radar data, the sea surface roughness is treated as short wavelength capillary waves riding on longer gravity or swell ocean waves. The frequencies and amplitudes of the capillary and gravity waves are affected by wind speed over the surface, sea currents and by the sea floor topography.

66. The generation of ocean wave spectra derived from SAR data is of both scientific and practical value. This information is used for periodic updates and verification of regional and global wind-wave forecast models. The timely knowledge of directional wave spectra is of practical value to marine transportation, fishing and naval activities. Wave measurements and wave impact on coastal areas could also be useful for coastal erosion research. Next to surface waves, internal waves are the most commonly observed features in SAR imagery. Internal waves owe their existence to vertical gradients of the water column, particularly at density interfaces. These waves are generated by the interaction of tidal currents and by abrupt changes in the seabed topography.

67. In addition to waves, SAR data can also provide variations of wind speed at the sea surface and estimates of heavy rainfall on the ocean. Surface eddies can be seen near strong currents and downstream of points of land while tidal flows at coastal inlets are prominently visible. Ice movement and areal coverage of the arctic and antarctic regions can be monitored accurately. On the basis of surface roughness, various types of ice (e.g. old, new) can be distinguished and estimates of their thicknesses can be obtained.

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F. Combined use of visible, infrared and microwave data

68. The merging of radar imagery with imagery from other sensor systems has proved to be useful in improving the identification of land cover elements present in an observed area and the mapping and monitoring of natural resources. Under a joint FAO/ESA case study project, visible and near infrared data from Landsat's MSS and TM sensors and from SPOT's HRV sensor have been combined with SAR data from SEASAT (1978) and from the SIR-A mission (1981) taken over the M'Saken and Cap Bon regions in Tunisia. The FAO/ESA project aimed at evaluating the use of data from various sources for agricultural land use mapping. The region of M'Saken is semi-arid with a flat topography and has olive plantations, cereals and vegetables. The Cap Bon region is also semi-arid but with topographic relief of up to 580 metres; this region has intensive irrigated agriculture with citrus plantations, vegetables, vineyards and cereals. In both regions, 75 per cent of the farms are smaller than 5 hectares and 90 per cent are smaller than 20 hectares.

69. The analyses of visual interpretation and digital classification of the images showed that field patterns of olive plantations (M'Saken) and citrus plantations/cereal fields (Cap Bon) were only identifiable on radar data; however, the density of the classes could not be extracted. Soil and water conversation banks which are long linear features approximately 1 metre wide, are only visible on SEASAT data because the illumination of the radar beam was perpendicular to the banks. Soil moisture variations were also only visible on radar data. On the other hand, identification of crops and their density of planting was only possible on the visible and infrared data. Thus, the digital classifications of the two areas, which are based on class and density identification, did not significantly improve when radar data was included.

70. The study concluded that the combined use of visible and near infrared and radar data for land use mapping has a strong potential for semi-arid land areas. However, the study indicates that the benefits come from extracting additional information not available from Landsat and SPOT data which is important to determine land suitability for specific agricultural use and not from an improvement of the crop or plantation identification. The study recommends that studies such as this one should be conducted for tropical areas as well.

71. Two similar studies under the same joint FAO/ESA project are being conducted in Guinea and Sierra Leone. The objective of these studies is to evaluate the usefulness of SAR data, combined with visible and near infrared data, in mapping mangrove and moist forests. At present, these studies are in the process of acquiring and incorporating ancillary data (topographic maps, field checking, digital terrain data) although preliminary observations indicate that swamps and riverain forests will be identifiable on SIR-A data.

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G. Remote sensing activities in the ECA and ESCWA regions

72. Although development can and does take place without surveys and maps, the lack of accurate surveying and mapping information in development planning and implementation can result in economic and environmental catastrophes. There is a strong correlation between the degree of development of a country and how well it is mapped at various scales. The type of economy and the main production areas that can be supported by the map products depends on the scale of the existing cartography. Thus, a pre-industrial type of economy based on extensive agriculture requires cartography at a 1:200,000 scale, an industrial economy based on consumer products requires a good knowledge of natural resources which can be derived from cartography at a 1:50,000 scale while the post-industrial economies are based on the provision of services for urban and regional planning that can be supported by Geographic Information Systems; these systems require information at scales as large as 1:10,000 and 1:1,000.

73. Most countries in the ECA and some of ESCWA regions are yet to be fully mapped at the basic scale of 1:50,000 that is necessary to develop or upgrade highway and railway transportation networks, identify and evaluate existing natural resources, increase food production where necessary, plan urban development and protect the environment from natural and antropogenic disasters. Space technologies, particularly remote sensing and the use of the Global Positioning System (GPS) to establish ground control for map revision and updating, can accelerate the process of completing the 1:50,000 cartography.

74. The General Organization of Remote Sensing (GORS) in Syria conducts studies and carries out projects in various applications fields. Such work has included a hydrological study of the Damascus basin and the Euphrates River and its reservoirs, geologic and volcanic studies, monitoring of the environment, archaeology and agriculture. Recent studies in the latter field have focused on land reclamation and its suitability for irrigation. In Saudi Arabia, as in Jordan, there are several remote sensing facilities located within the ministries that deal with agriculture, water resources, natural resources and mineral and oil exploration. In both countries, remote sensing has been successfully used in finding water resources, mineral deposits and in locating prospective mineral and oil areas and in coastal and environmental studies.

75. The Regional Centre for Services in Surveying, Mapping and Remote Sensing (RCSSMRS), located in Nairobi, Kenya, provides services, carries out studies and research and provides training for nationals of Member States in surveying, mapping and remote sensing. The Centre also provides advisory services, upon request, on various issues within its sphere of competence to Governments of ECA member States. The Centre has embarked on a joint project with FAO and the Intergovernmental Authority for Drought and Desertification (IGADD) with the sponsorship of the Government of Japan, in an effort to build up subregional and national capabilities in the use of remote sensing data for early warning food security monitoring and forecasting. At present this is one of the main goals of the Centre.

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H. Search and rescue services

76. COSPAS-SARSAT is a cooperative programme between Canada, France, the Soviet Union and the United States that provides assistance in search-and-rescue operations for maritime, aeronautical and land vehicles anywhere in the world. Beacons fitted on the vehicles send a distress signal to one of four satellites that are operated by the Soviet Union and the United States. The satellites process or relay the distress signals to a mission control centre where the beacon positions are determined. From these centres, the information is forwarded in the form of an alert to rescue coordination centres. Since its inception in 1986, the COSPAS-SARSAT programme has been instrumental in saving more than 2,500 human lives.

77. Vital to the COSPAS-SARSAT programme is the quick response provided by satellite communications. It has been shown that when the victim of an aircraft accident needs to wait for the rescuers for more than two days, the probability of survival is only 10 per cent. The same probability rises to 60 per cent when the rescue takes place within eight hours. Mean survival time at sea is highly dependent on water temperature. Mean survival time in waters of 5-10°C is less than 3 hours; this same time is less than 6 hours in waters of 10-15°C and less than 12 hours at 15-20°C.

78. Following negotiations with the COSPAS-SARSAT Programme, the Council of Ministers of Spain has approved the installation at the Maspalomas Space Station of a Local User Terminal (LUT) for the COSPAS-SARSAT satellite system. This LUT will provide needed coverage over land routes of desert areas in the Sahara and Sahel region, air and maritime routes to Europe from South America and South and Central Africa as well as over the fisheries zone in the Atlantic Coast of Africa region.

I. Future radar satellites

79. Canada's RADARSAT will carry one SAR instrument that will operate in the C-band with multi-mode single polarization. RADARSAT will be capable of imaging swaths 35 to 500 km in width with associated resolutions of 10 to 100 m. The instrument has been designed for imaging capability at a variety of incidence angles (approximately 20° to 50°). The spacecraft has been designed for a five-year lifetime and is scheduled for launch in December 1994. The orbit is planned at 800 km, sun-synchronous, dawn-to-dusk, with a 24-day repeat visit and a 3-day sub-cycle. The SAR antenna will point North but the spacecraft will be capable of rotating 180° about its yaw axis in order to obtain images of Antarctica. Because it will carry on-board tape recorders, RADARSAT will be able to provide radar imagery of the entire globe.

80. RADARSAT mission operations will be coordinated by a mission management office (MMO) which will serve as an interface between the user community, the mission control facility and the ground receiving and processing facilities. MMO will monitor the entire data distribution, which will be carried out mainly by RADARSAT International, a private-sector corporation. The image

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products to be provided will be of the following three types:

(i) geo-referenced products, i.e., standard images with systematic geometric corrections; (ii) geo-coded products, i.e., images that are resampled and rotated to conform to standard map projections; and (iii) special products, e.g., unprocessed signal data, single-look (full-resolution) real or complex image files and analysis of external calibration files. The image products will generally be available in both photographic and digital forms. The imaging modes for RADARSAT will include Standard (30 m resolution), Wide Swath (30-50 m resolution), Fine Resolution (10 m resolution), Extended (20-60 m resolution) and ScanSAR (50-100 m resolution).

81. As part of the International Space Station programme, the United States will be launching two polar platforms which will be used in conjunction with polar platforms launched by ESA and Japan and with a series of geostationary satellites to monitor the global environment. This will be part of the United States Earth Observation System (EOS), the purpose of which is to collect a consistent set of global environmental data over a period of 15 years in order to study global changes such as those due to the greenhouse effect and to changes in the ozone layer. An Advanced Microwave Sounding Unit (AMSU) for atmospheric water vapour and temperature profiles and an Advanced Microwave Scanning Radiometer (AMSR), for measuring sea surface temperature and observing ice, snow and precipitation, are also being planned as part of the system.

82. In the mid-1990s, ESA will be participating in the International Space Station along with the United States, Canada and Japan. The ESA components will include a European module attached to the main space station and the Columbus Polar Platform currently scheduled for launch in 1997 into a near polar orbit. Among the remote sensing systems being considered for use on the Polar Platform are an imaging radar system, a radar altimeter and a scatterometer, along with a number of systems operating in the visible and infrared bands. Data from the Polar Platform will be transmitted either directly to ground stations or via ESA data relay satellites when the Platform is outside the range of a ground station.

83. A major purpose of the Polar Platform microwave sensors will be to ensure continuity with the systems scheduled to operate in the early 1990s, in particular with ERS-1 and ERS-2; its priority will therefore be ocean observations. However, the imaging radar would have a variable incidence angle, allowing the observations of land areas at high incidence angles for geomorphological studies as well as observations of ocean features at low incidence angles. The system would have several operating modes, ranging from high-resolution (10 m) imaging of a narrow swath (30 km) to low-resolution (1 km) imaging of a wide swath (500 km). Like ERS-1, the Polar Platform radar would operate in the C-band.

84. A design concept for a radar satellite system for tropical forest monitoring was presented. The design would avoid the three major obstacles that could preclude large scale use of currently planned space radars: high primary data cost; complex and centralized ground segment infrastructure; and

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a less than optimum radar wavelength. The proposed system is specified based on existing regional capabilities in data reception, processing, and utilization. The space segment would use existing AVHRR class data telemetry (625 Kbps), and partial on-board pre-processing of the P-band (75 cm) synthetic aperture data. Aggregate coverage of the Earth's tropical forests twice a year would be achieved with 10 look imagery of 20 km usable swath width and pixel resolution of 50 metres. Image processing would require only high end PC-class hardware which could be distributed over many regional centres.

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Annex

PROGRAMME OF THE WORKSHOP

<u>Date</u>	<u>Time</u>	<u>Subject</u>	<u>Speaker</u>
Monday 10 June	0900-0920	Opening ceremony	
		<u>Welcome addresses:</u>	
		United Nations	S. Camacho
		Food and Agriculture Organization	J. F. Dallemand
		European Space Agency	J. Moreira
		Instituto Nacional de Técnica Aerospacial	J. Melián
	0920-1000	<u>Keynote address:</u> Surveying and mapping in Africa - From conventional to space technologies	O. L. Adekoya (Nigeria)
		<u>Fundamentals of microwave remote sensing</u>	
		Chairman: T. Engman (NASA)	
	1000-1045	Overview of microwave remote sensing	J. Moreira (ESA)
	1100-1145	Principles of microwave radiometry and microwave interaction mechanisms	J. Moreira (ESA)
	1145-1230	Theory of Synthetic Aperture Radar	K. Raney (CCRS)
	1400-1445	Radar image characteristics: processing and analysis	J. Moreira (ESA)
		<u>Radar data applications (potential and limitations)</u>	
		Chairman: J. Baraza (Kenya)	
	1445-1530	Review of radar remote sensing for forest management	K. Raney (CCRS)
	1545-1630	Microwave applications for weather, climate and hydrology	T. E. Engman (NASA)

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<u>Date</u>	<u>Time</u>	<u>Subject</u>	<u>Speaker</u>
	1630-1715	Oceanographic applications of radar data (sea-state, ocean circulation and ocean surface topography)	M. Cantón U. Las Palmas
Tuesday 11 June		<u>Integration and analysis of data from different sensor systems</u>	
	0900-0945	Use of microwave and optical data for land use mapping: M'Saken, Tunisia Case Study	J. F. Dallemand (FAO)
	0945-1030	Thematic analysis of geocoded data: Case studies in Tunisia, Guinea and Sierra Leone	J. F. Dallemand (FAO)
	1045-1130	ESA's ERS-1 Programme	B. Pfeiffer (ESA)
	1130-1200	Reception of ERS-1 data	R. Charlan (INTA)
	1200-1230	Processing of ERS-1 data	M. Sosa (INTA)
		<u>Remote sensing activities in Africa and the Middle East</u>	
		Chairman: O. L. Adekoya (Nigeria)	
	1400-1445	Remote sensing activities in Saudi Arabia's Ministry of Agriculture and Water	F. Arrubah Saudi Arabia
	1445-1515	Activities of the General Organization of Remote Sensing	M. Al-Malki Syria
	1530-1600	Remote sensing applications to geology and mineral/oil exploration	B. F. Sunna Jordan
	1600-1645	Remote sensing activities in the Regional Centre for Services in Surveying, Mapping and Remote Sensing	J. Baraza Kenya
	1645-1730	ESA contributions to the United Nations-ISY activities: collection, analysis and application of satellite data sets for project management in Africa	B. Pfeiffer (ESA)

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<u>Date</u>	<u>Time</u>	<u>Subject</u>	<u>Speaker</u>
Wednesday 12 June		<u>Space data received by the Maspalomas Station: Local applications</u>	
		Chairman: B. F. Sunna (Jordan)	
	0900-0945	Fisheries and satellite observations of the NW coast of Africa	O. Llinas Spain
	0945-1030	Oceanographic applications of passive sensor data in the Canary Islands area	A. Hernandez M. Cantón U. Las Palmas
	1045-1130	Operation of the Maspalomas Station: ERS-1 expansion	J. Melián (INTA)
	1130-1230	Visit to the Maspalomas receiving station facilities	INTA
	1300-2000	Tour of the Island	
Thursday 13 June		<u>Instrumentation, measurements and application possibilities in microwave remote sensing: past experience and future development</u>	
		Chairman: J. F. Dallemand (FAO)	
	0900-0945	Applications from the SIR-A, SIR-B missions with specific examples from Africa/Middle East	T. E. Engman (NASA)
	1045-1130	Canada's Radarsat programme	K. Raney (CCRS)
	1130-1215	The Polar Platforms	B. Pfeiffer (ESA)
	1215-1300	The Earth Observing Systems	E. T. Engman (NASA)
		<u>Regional and international space activities</u>	
		Chairman: J. Moreira (ESA)	
	1400-1445	The COSPAS/SARSAT search and rescue programme	P. Dumont (CNES)

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<u>Date</u>	<u>Time</u>	<u>Subject</u>	<u>Speaker</u>
	1445-1530	Spain's COSPAS/SARSAT LUT station	J. Melián (INTA)
	1545-1630	A regional centre for space science and technology education	A. Abiodun United Nations
	1630-1715	Discussion of participants' experience in microwave remote sensing	
Friday 14 June		<u>Working Group session</u>	
		Chairman: K. Raney (CCRS)	
	0900-1230	(1) Data accessibility and availability	
		(2) Applications development	
		(3) Required education and training	
		Rapporteur: Y. Murakami (United Nations)	
		Rapporteur: S. Camacho (United Nations)	
	1400-1600	Working Group (continued)	
	1600-1630	Summary and evaluation of the Workshop	Participants
	1630	Closing ceremony	UN/FAO/ESA/INTA
